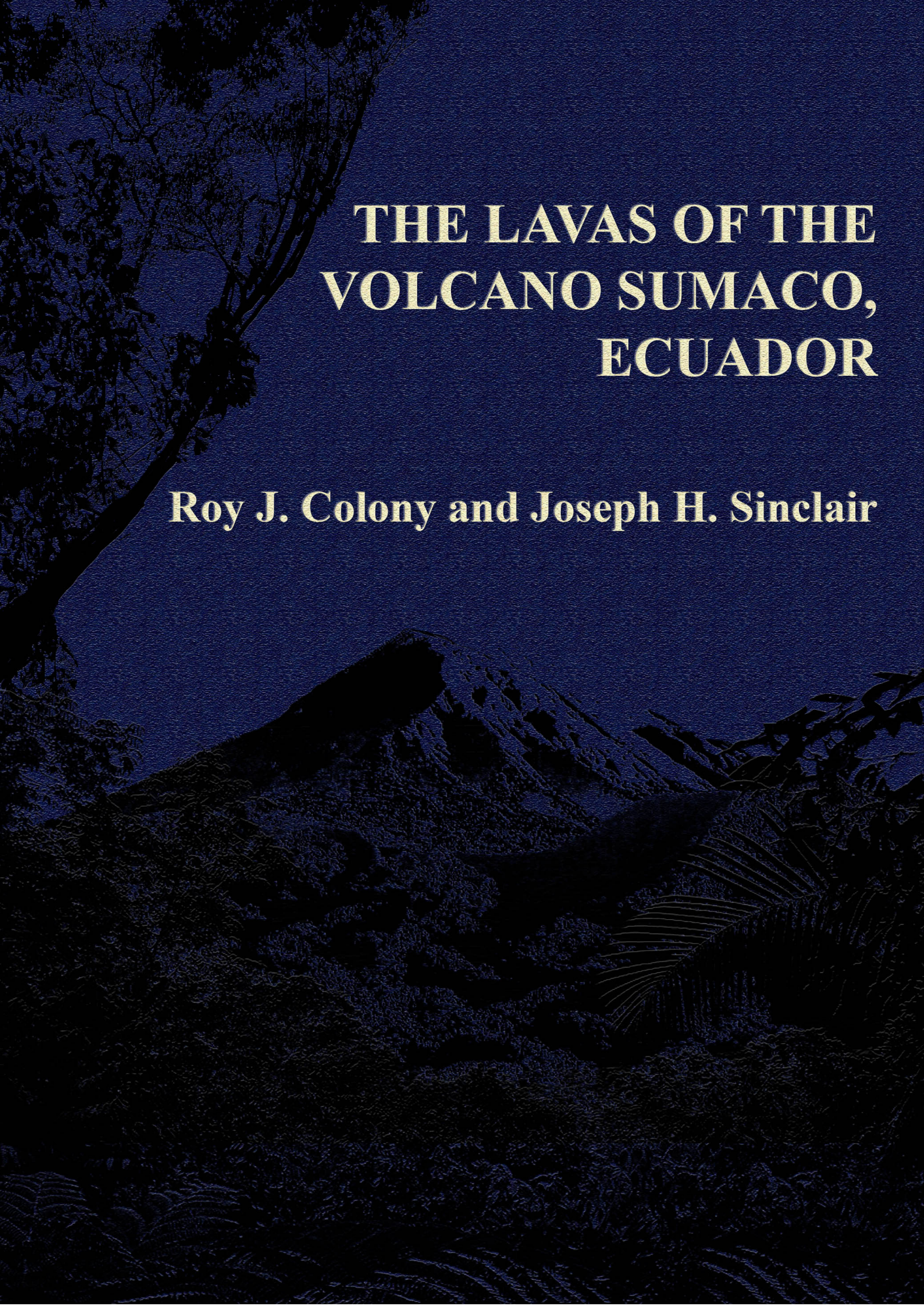

THE LAVAS OF THE VOLCANO SUMACO, ECUADOR

Roy J. Colony and Joseph H. Sinclair

[American Journal of Science October 1928, s5-16 (94) 299-312]

THE LAVAS OF THE VOLCANO SUMACO, EASTERN ECUADOR, SOUTH AMERICA

by

ROY J. COLONY and JOSEPH H. SINCLAIR

CONTENTS

INTRODUCTION **1**

THE LAVAS OF SUMACO **3**

Petrographic Description **4**

Specimen No. 1: Tephrite **4**

Specimen No. 2: Tephrite **6**

Specimen No. 3: Vitrophyric tephrite **7**

Specimen No. 4: Andesitic tephrite **9**

Specimen No. 5: Basalt **9**

Specimen No. 6: Fossiliferous limestone **10**

Specimens Nos. 7, 8, 9: Andesitic tephrites **10**

Comment on analyses **11**

FIGURES

Figure 1: Sketch map of Ecuador showing approximate location of Sumaco volcano **1**

Figure 2: Photograph of Sumaco **3**

Figure 3: Photomicrograph del specimen No. 1 **5**

Figure 4: Photomicrograph del specimen No. 2 **6**

Figure 5: Photomicrograph del specimen No. 7 **11**

Location map of the volcano Sumaco **12**

TABLES

Table 1: Chemical analysis and Norm of specimens Nos. 1, 2, 3 y 7 **8**

INTRODUCTION

In February, 1541, Gonzalo Pizarro, the brother of the famous conqueror of Perú, left Quito at the head of an expedition whose object was to conquer and explore the "land of cinnamon", a region reported to be situated at the east base of the Andes Mountains, and to be rich beyond belief not only in cinnamon, but in gold and other precious metals. The expedition ended in a disastrous return to Quito after many months of fruitless wandering in the rainy jungles of the headwaters of the Amazon River. It was not, however, a complete failure for Francisco Orellana, one of Pizarro's captains, becoming detached with a few companions from the main party in December, 1541, descended for the first time the Río Napo to the Amazon and then the main stream to the Atlantic, thus accomplishing one of the great geographic feats of the sixteenth century.

According to historians[1] the members of the expedition of Pizarro made no stop of any length after leaving Quito till they came to a "Provincia" called "Zumaco, which is on the slopes of a high volcano"; here they stayed two months and in the record of their journey[1] is the first historical mention of the volcano Sumaco.

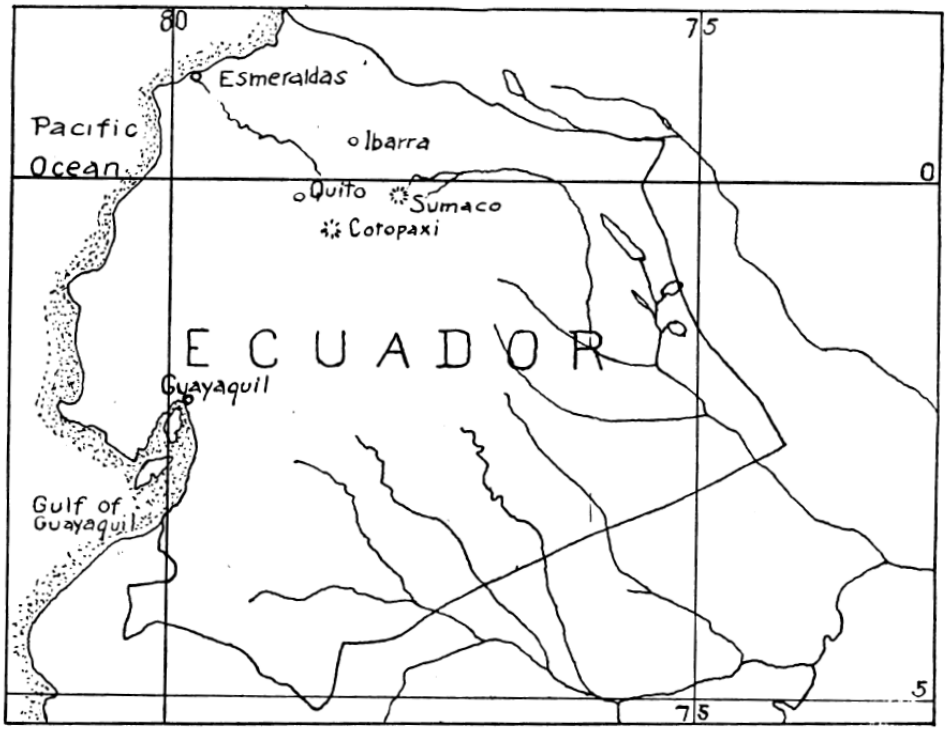

Fig 1. Sketch map of Ecuador showing approximate location of Sumaco volcano (see at the end the updated map)

[1] López de Gomara, Francisco, Primera y Segunda Parte de la Historia General de las Indias. Zaragoza, 1552. Chapter 143 of the "Primera Parte"
Zarata, Augustin de, Historia del Descubrimiento y Conquista del Perú. Antwerp, 1555. Book. 4, chapter 2.

Statements regarding the volcano and its location have since then appeared from time to time[2] and Jiménez de la Espada describes the crater of the volcano as having a diameter of 100 meters. Some of the early explorers have mapped the volcano, but in no case is it correctly located on their maps[3], nor do Theodor Wolf (1892), Vacas Galindo or Fleming (1912) show it on their maps of Ecuador.

The geologists Joseph H. Sinclair and Theron Wasson, while descending the Río Napo in 1921, and using Wolf's map of Ecuador, were naturally considerably surprised, when on September 9, 1921, at a point forty-four miles below the village of Napo, they noted thirty-one miles to the northwest a lofty, cone shaped and isolated peak, rising high above the Amazon forests. From the traverse of the Río Napo between Napo and the mouth of the Río Coca, and from a traverse from Napo north through Tena and Archidona to the base of the Guacamayos Range, the exact position of the volcano was found by intersections and its elevation by vertical angles, to be 0°32' south latitude, 77° 38' west of Greenwich, and its highest point 12670 feet above the sea[4]. The location is shown approximately on the accompanying sketch map, Fig. 1. In 1925 Commander George M. Dyott, while descending the Río Napo, visited this mountain[5] (Fig. 2).

On comparing the accounts of Jiménez de la Espada and Dyott, it seems probable that a period of volcanic activity occurred between 1865 and 1925, for Jiménez de la Espada describes the crater as being over 328 feet wide, while Dyott gives it a diameter of about 900 feet; and while the former describes a great opening in the crater to the south, Commander Dyott states that the crater is perfectly formed. Unfortunately, we have no comparative data on the depth of the crater.

2 Ordoñez de Cevallos, Pedro, Viaje del Mundo, Madrid. 1614.
Jiménez de la Espada, Marcos, Primeros Descubrimientos del País de la Canela, El Centenario, Madrid, 3, 437-457, 1892.
Rice, Alexander Hamilton, From Quito to the Amazon via the Río Napo, The Geog. Jour., 21, 401-408, 1903.

3 Maldonado, Pedro, Carta de la Provincia de Quito, 1750.
Díaz de la Fuente, Appolinario, Mapa Geográphico de la Provincia de Quixos, 1777.
Humboldt, Alexander, Atlas Géographique et physique des régions équinoxiales du nouveau continent, Paris, 1814-1834, Plate XI.
Villavicencio, Manuel, Carta Corográfica de la República del Ecuador, New York, 1858

4 Sinclair, J.H., and Wasson, T., Explorations in Eastern Ecuador, The Geog. Review, 13. 190-210, 1923

5 Dyott, G. M., On the Trail of the Unknown in the Wilds of Ecuador and the Amazon, New York, 1926

THE LAVAS OF SUMACO

Commander Dyott collected specimens at our request from Sumaco and thin sections were made of these. The petrographic examination of these thin sections has revealed that the magma of the volcano Sumaco is distinguished by the presence of feldspathoid minerals.

The fact that the lavas of the volcanoes of Ecuador have been subjected of a great deal of petrographic study indicates that the Sumaco magma is unique in Ecuador, for these minerals could not have been overlooked in the numerous specimens of rock examined, especially by German petrographers, from the volcanoes Cotopaxi, Pichincha, Tungurahua, etc.

Fig 2. Photograph of volcano Sumaco, taken in 1925 by Commander Georg M. Dyott from the pueblo of San José, Eastern Ecuador

According to Iddings[6] the lavas of Ecuador are chiefly andesites, grading into basalts in some instances; in certain localities dacites and rhyolites are common, but Iddings does not mention the occurrence of any feldspathoid-bearing lavas, nor is any reference made to such lavas in the literature descriptive of the petrography of Ecuador rocks. Nephelite syenites are more or less common in Brazil, and they are mentioned as occurring in French Guiana and Patagonia. On the eastern flanks of the Andean ranges in Argentina and Patagonia nephelite-bearing lavas are associated with the usual Andean volcanics, and phonolites, nephelite-basalts, leucite-basalts and tephritic basalts occur in Brazil[7].

6 Iddings, J. P., Igneous Rocks, Vol. II, p. 441.

7 Described in various papers by O. A. Derby, F. Graeff, E. Hussak, J. Machado, Hunter and H. Rosenbusch, E. O. Hovey, F. E. Wright, References cited by J. P. Iddings, Igneous Rocks, Vol. II, p. 486

The volcano of Sumaco differs from all other volcanic peaks of Ecuador in that it is isolated from the main range of the Andes, that it rises from a comparatively low elevation on the Amazon plain, and that it carries on its flanks uptilted sediments through which it has broken. From the description of the general geology of the region by Sinclair and Wasson [8]it is clear that the volcano was born at a date subsequent to the deposition of the late Cretaceous strata around its base. Its uneroded condition indicates that it is of recent origin and the comparison above made of descriptions of the condition of the crater in 1865 and 1925 point to the possibility of activity between those dates.

Because this is the first petrographic description of any rocks from this volcano, which is the first volcanic center known east of the Andes in Ecuador, the following descriptions of the specimens collected by Commander Dyott are offered in detail. The observations are based on a petrographic study of nine thin sections cut from the specimens collected by Commander Dyott from the flanks of the volcano and from the rim of the crater, and on analyses of four of the lavas; the specimens collected were very small so that but little was left of each sample after the thin sections were cut. With the exception of No. 6, which is a foraminiferal limestone, all the rocks are andesitic and basaltic lavas, the striking thin is the presence of feldspathoids in all but one of the lavas. In this respect they differ from the usual Andean volcanics of Ecuador, since no feldspathoid-bearing lavas have been found in Ecuador, so far as the writers know. While in a general way all the specimens of the lavas are similar, there is sufficient difference between them to warrant individual descriptions, more especially since rocks of this character have never before been found in this locality.

Petrographic description

- ***Specimen No. 1,*** from the rim of the crater on the summit of Sumaco, is a moderately strongly porphyritic tephrite carrying phenocrysts of plagioclase feldspar ranging from andesine to labradorite in composition, which exhibit a striking zonal development, complex twinning and which contain zonally distributed inclusions. Pale green, very slightly pleochroic phenocrysts of augite are as plentifully distributed as are the plagioclase phenocrysts. The augite crystals are occasionally twinned; a few of them show the "hour-glass" structure and zonal development as well. In those sections showing the most marked pleochroism the color changes range from pale green to shades of yellowish green. Olivine is so very sparingly distributed that only one crystal was seen, associated with augite that occurs as a rim or border around it. The rock carries considerable magnetite in large and small grains, and a little accessory apatite that is strongly colored brown by what is judged to be finely disseminated magnetite dust.

[8] Manuscript in the hands of the editor of the Bulletin of the American Association of Petroleum Geologists.

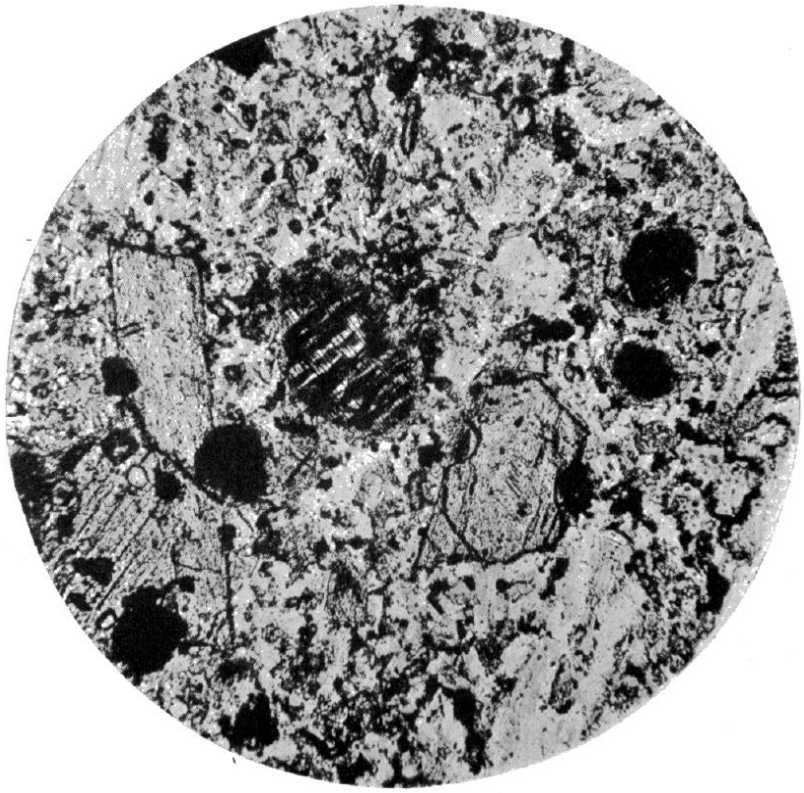

Fig. 3. *Photomicrograph of Specimen No. 1. Ordinary Light, ×54.* Showing one of the haüynite crystals, with cleavage, filled with fine, dark included matter. The character of the groundmass is shown a little more clearly at this higher magnification and the augite phenocrysts together with the clear plagioclase crystals may be readily seen.

The groundmass is composed of minute augite prisms, small laths of plagioclase as well as slightly larger crystals of plagioclase that are much less calcic in composition than the large phenocrysts, with shells of alkalic feldspar around them; small crystals of orthoclase, little square and rectangular crystals that have the general appearance and habit of nephelite and imperfect dodecahedral crystals of haüynite showing strongly marked cleavage with inclusions oriented along the cleavages and distributed in fine dust-like particles that make some of the crystals almost opaque (Fig. 3). These crystals of haüynite are surrounded with a shell of isotropic substance that may possibly be of slightly different composition, and into which the cleavages do not usually extend. In addition, there are altered turbid spots that seem in many places to be interstitial in their distribution; these may be altered sodalite, although the identification is doubtful. Megascopically the rock is moderately porphyritic, dark gray in color, with abundant small phenocrysts of plagioclase and augite. A weathered exterior shell 1/16 inches thick surrounds the dark gray unweathered interior.

- ***Specimen No. 2,*** taken from another part of the rim of the crater, is also a tephrite. The phenocrysts of plagioclase are more abundant than the augite; they have a decided fluxional arrangement and they are clear and fresh, complexly twinned after the albite, pericline and Carlsbad laws and they exhibit zonal growth and contain crystal inclusions, glass inclusions and liquid and gas inclusions, all more or less well oriented. A few of the plagioclase crystals are slightly corroded, but resorption is not a prominent factor. Some of them are grouped so as to form compound phenocrysts and in some cases the individual crystals in the groups are slightly separated from one another by brown interstitial glass (Fig. 4). Very faintly pleochroic, beautifully idiomorphic crystals of grayish-green augite constitute the prominent ferromagnesian component of the rock. These crystals have moderate birefringence ($N^{\gamma} - N^{\alpha} = \pm 0.020$), with maximum extinction angles of 36°. They are optically positive, with notable dispersion, and occasional crystals exhibit very obscurely both the “hour-glass” structure and zonal structure.

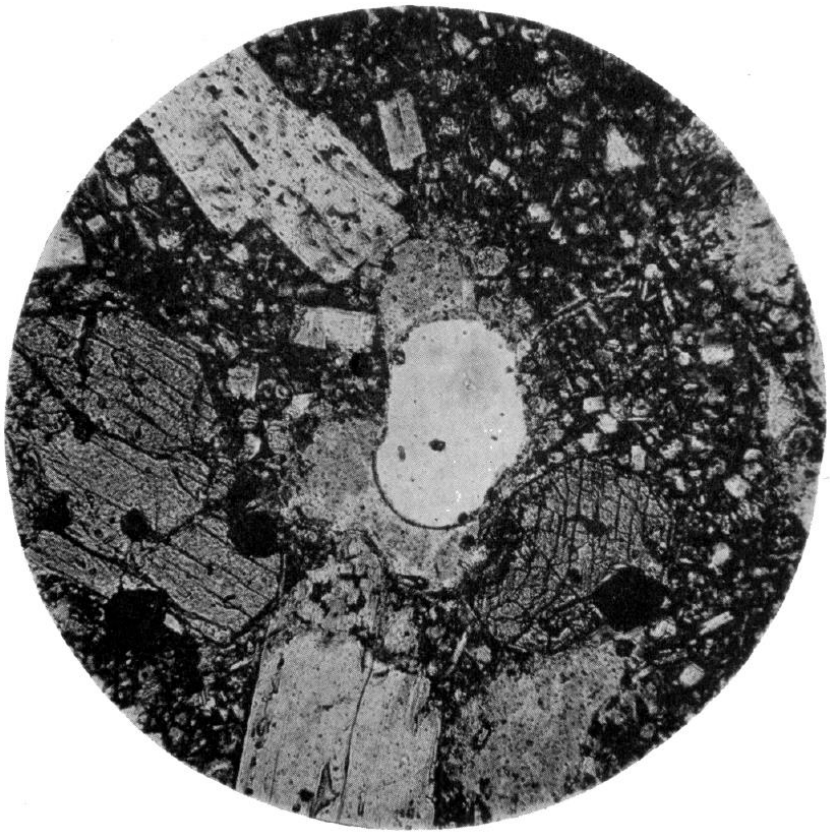

Fig. 4. *Photomicrograph of Specimen No. 2. Ordinary Light, ×100.* The groundmass is a reddish glass, black in the picture, filled with little rectangular crystals, judged to be nephelite, and minute needles of plagioclase. Clear unaltered phenocrysts of plagioclase and augite are both shown in the field, and in the center of the pictures a vesicle in clear colorless glass may be seen. An irregular patch of the same clear glass occurs in the lower right part of the photomicrograph.

The groundmass is composed of a reddish-brown glassy base filled with multitudes of little square, rectangular and hexagonal crystals that resemble nephelite, minute plagioclase laths, and a feldspathoid occurring in crystals that have a dodecahedral habit, in some of which cleavage is emphasized by oriented inclusions, whereas others exhibit the blue color characteristics of haüynite; in addition, there are other euhedral, clear isotropic crystals that resemble analcite. Olivine and apatite occur very sparingly, but magnetite is a prominent accessory. The rock is decidedly vesicular, the vesicles always occurring in clear, colorless transparent irregular isotropic areas that look like glass and that have an index of refraction as high as the plagioclase crystals. This specimen differs from No. 1 in that it is somewhat more feldspathic, shows flowage much more distinctly and carries more glass in the groundmass. The hand specimen of No. 2 is darker and considerably more vesicular than No.1. The little plagioclase phenocrysts exhibit a directional arrangement due to flowage, and the haüynite occurs in bluish crystals that are almost as large as some of the smaller feldspars. Both Nos. 1 and 2 have essentially the same chemical composition, as shown by the results of the chemical analyses, Table 1.

- ***Specimen No. 3,*** from the slopes of the volcano, is a vitrophyric tephrite whose groundmass is somewhat altered but whose phenocrysts are perfectly fresh, as are the tiny plagioclase microlites in the altered glassy groundmass. The rock is as vesicular as No. 2; the vesicles are always connected with and are distributed in colorless, isotropic, irregular areas of glass, similar to those in sample No. 2. The feldspar in this rock is confined to the groundmass through which it is distributed in the form of labradorite microlites. Pale, almost colorless augite, with moderate birefringence ($N^{\gamma} - N^{\alpha} = \pm 0.018$), moderately strong dispersion, optically positive character and with maximum extinction angles of 40°, is sparingly disseminated in idiomorphic crystals and groups of crystals. A feldspathoid with the habit of haüynite is almost as abundant as the augite; the crystals are as large as the augite crystals and form one of the striking features of the rock. Most of them have good cleavage, some of the smaller ones carry oriented inclusions, and in a few instances, they show resorption effects. These blue crystals are so abundant in the hand specimen that their index of refraction was determined in the powdered rock by the immersion method. A number of determinations gave an index of 1.503 ± 0.005, corresponding to a somewhat calcic haüynite. The index is higher than the indices given for haüynite by Larsen [9]and Iddings[10]. Larsen gives 1.496 as the index of refraction of haüynite; Iddings gives 1.4961 as the index of blue haüynite from Niedermendig. Winchell [11] states that the index varies from 1.430 to 1.509, depending on the percentage of lime. A very small amount of magnetite, olivine and apatite occur as minor accessories, together with a strongly pleochroic light yellowish-brown hornblende.

9 Larsen, E. S., The microscopic determination of the nonopaque minerals, Bull. 679, U.S. Geol. Surv., 1921

10 Iddings, J. P., Rock Minerals.

11 Winchell, N. H., and Winchell A. N., Elements of Optical Mineralogy, 1909

TABLE 1

	No.1	No. 2	No.3	No. 7
SiO_2	52.88	51.74	46.14	50.90
Al_2O_3	18.96	19.78	18.04	18.88
Fe_2O_3	2.92	3	6.73	1.82
FeO	2.88	2.03	1.44	3.20
MgO	2.22	2.26	4.91	2.61
CaO	6.40	6.33	9.28	6.45
Na_2O	5.09	5.24	5.08	4.76
K_2O	4.05	3.74	2.91	3.13
H_2O -	0.85	0.75	0.24	1.48
H_2O +	1.33	1.54	0.66	1.80
TiO_2	0.68	0.84	0.68	0.76
P_2O_5	0.42	0.52	0.98	0.78
SO_3	0.01	0.05	0.47	0.21
MnO	0.13	0.13	0.15	0.13
BaO	0.42	0.45	0.30	0.32
Total	**99.24**	**98.40**	**98.01**	**97.23**

Analyses by Ledoux and Company, New York City

NORMS

	No.1	No. 2	No.3	No. 7
Or	23.91	22.24	17.24	18.35
Ab	30.39	30.39	14.67	34.58
An	16.96	19.18	19.46	21.68
Ne	6.82	7.67	13.63	2.27
S. S.	-	-	0.85	0.43
Di	10.50	7.78	16.63	5.40
Ol	1.81	1.47	3.22	5.20
Mt	4.18	4.41	3.02	2.55
Il	1.37	1.67	1.37	1.52
Hm	-	-	4.64	-
Ap	1.01	1.34	2.35	1.68

No. 1. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.
No. 2. Andesitic Tephrite, II, 5, 2, 4. Akerose; rim of crater.
No. 3. Vitrophyric Tephrite, II, 6, 3, 4. Salemose; slopes of volcano.
No. 7. Andesitic Tephrite, II, 5, 3, 4. Andose; 2000 feet down the slope.

This specimen differs from the other tephrites of this series in the presence of phenocrysts of haüynite instead of feldspar, in the restriction of feldspar to the groundmass, where it is distributed in the form of microscopic needles, and in the glassy character of the rock. The composition of the rock is likewise different as shown by the analysis, Table 1. Silica is lower, lime and magnesia higher and sulphuric anhydride is higher. These differences are reflected in the mode of the rock. The rock is dark red-brown in color, somewhat vesicular, very fine in texture, and contains numerous small, blue crystals of haüynite ranging in size from 0.03mm to 1mm, and larger phenocrysts of augite.

- ***Specimen No. 4,*** also from the slopes of the volcano, is essentially an andesitic tephrite. It is porphyritic with a typical andesitic groundmass consisting of minute plagioclase laths of andesine make-up, arranged in characteristic flowage lines in a more or less isotropic base that is in part glass – the "hyalopilitic" structure exhibited by many andesites. The phenocrysts are large clear labradorite crystals that possess the usual complex twinning, large, pale augite crystals with a very moderate birefringence and brown basaltic hornblende, less plentiful than either the labradorite or the augite. Magnetite forms one of the prominent accessories, and apatite occurs in unusually large crystals that are mor or less strongly colored violet-brown to smoky brown by included magnetite or ilmenite dust; in some places these inclusions are so concentrated as to render the crystal black and opaque in spots. Haüynite is distributed through the groundmass in clear, isotropic small idiomorphic crystals that occasionally show a little resorption; the largest of these have dimensions of the magnitude of 0.25 mm. A few tiny square crystals doubtfully referred to nephelite are also scattered through the groundmass. The rock is slightly vesicular, and, like the other rocks of the series, the vesicles are commonly connected with irregular, clear, colorless isotropic areas that may be glass, but which in this rock have an index of refraction lower than balsam (< 1.535). The phenocrysts are considerably larger than those in the other samples and the rock is strikingly andesitic texturally, although the feldspars and the pyroxenes favor a basaltic composition. Megascopically the rock is very dark in color, strongly porphyritic, and very fine as to groundmass. The phenocrysts are moderately large plagioclase crystals attaining maximum dimensions of 6.0 mm, and augite crystals that are almost as large.

- ***Specimen No. 5,*** likewise from the slopes of the volcano, has a very pronounced red color due in part to incipient oxidation of the glassy portion of the groundmass and in part to very abundant, minute red crystals disseminated in the groundmass. These crystals have monoclinic forms, strong birefringence, and strong relief. Most of the crystals have approximately parallel extinction, but occasional ones gave angles as high as 12°, dependent on their orientation. They exhibit strong absorption in a direction perpendicular to their elongation, in this respect behaving like tourmaline. Occasionally one crystal penetrates another, simulating the cruciform twinning of staurolite; these are probably accidental penetrations, however, and not twins. They are red-brown in color, but the color is spotty and variable in distribution. They may be iron-rich amphibole or pyroxene crystals, with an unusual absorption behavior, but we are not certain of their identity. They are very minute and do not give any very satisfactory optical reactions. The rock is otherwise normal in its make-up, consisting of basic plagioclase both as phenocrysts and as small laths in the groundmass, arranged in flowage lines; light-colored augite with moderate birefringence, very sparingly distributed; and magnetite, olivine, apatite, and yellowish-brown, beautifully pleochroic basaltic hornblende as accessories.

No feldspathoid minerals were observed in this rock, which differs in this respect from all of the other specimens submitted. The rock is a normal basalt. The feldspar, pyroxene and hornblende are perfectly fresh; all of the oxidation is confined to the groundmass. Even the olivine is but slightly attacked, some of it exhibiting rims of limonite. The fine dark red-brown groundmass of the specimen has suffered incipient oxidation, but all of the phenocrysts are fresh and unaltered. Like the other lavas of this series, the rock is vesicular, some of the vesicles being in a colorless glass whose index lies very close to 1.535.

- ***Specimen No. 6,*** taken from the sediments near the east base of the volcano Sumaco, is entirely different in origin and composition from all the other eight samples. This is a fossiliferous limestone containing foraminifera, bryozoa, shell fragments, all replaced by calcite, and yellow to brown fragments that may represent the carapaces of crustacea. It is difficult to identify the fossils in thin section, but Globigerina, Nodosaria, Cyclomina, Gümbelina, Textularia and Bryozoa were recognized. These forms are distributed in a fine carbonate matrix that is turbid with what is probably argillaceous matter. Considerable pyrite is distributed through the rock in fine granular aggregates, as individual crystals, and in veinlets; small black grains, that may possibly be bituminous matter, are sparingly disseminated. In places, some of the pyrite has oxidized to reddish-brown limonite.

- ***Specimens Nos. 7, 8 and 9.*** All of these samples were collected from the slopes of the volcano; No. 7 came from a point about 2000 feet down the slope. They are all andesitic tephrites with essentially the same compositions, and with only slight textural differences. The groundmass of No. 7 is partly glassy, with fine needles of moderately basic plagioclase feldspar and minute prisms of green augite distributed through it. The groundmass, consisting of a glassy base and thickly disseminated matted needles of plagioclase, and minute augite prisms, has the "hyalopilitic" structure common to many andesites. This feature is especially striking in specimen No. 8; the groundmass of No. 9, however, is composed of somewhat larger plagioclase needles than those distributed in the glassy bases of Nos. 7 and 8, although even No. 9 is also beautifully hyalopilitic.

All of these specimens are moderately porphyritic. The phenocrysts consist of large, clear, plagioclase crystals that have compositions ranging from basic andesine to labradorite; they are complexly twinned after the albite, Carlsbad, pericline, and in a few cases, the Baveno laws. Many of them exhibit zonal growth and a zonal distribution of inclusions. The plagioclase microlites in the groundmass are mor acid than those constituting the phenocrysts. Augite occurs both as phenocrysts and as minute prisms in the groundmass in all three of these rocks, and all carry a little brown basaltic hornblende also. The hornblende, more especially in No. 9, has been partly resorbed with the development of finely granular magnetite as a resorption product. Haüynite is an accessory common to all three of these rocks. In Nos. 7 and 9 it is slightly brownish in color, with very dark margins and pronounced cleavage in some instances (Fig. 5). The haüynite in No.8 is not so plentiful; the color is pale blue, with deeper blue margins; even the brownish haüynite, especially in No.7, is occasionally slightly bluish in the centers. Unusually large crystals of brown apatite form very striking accessories in all three of these rocks, and magnetite is a prominent component.

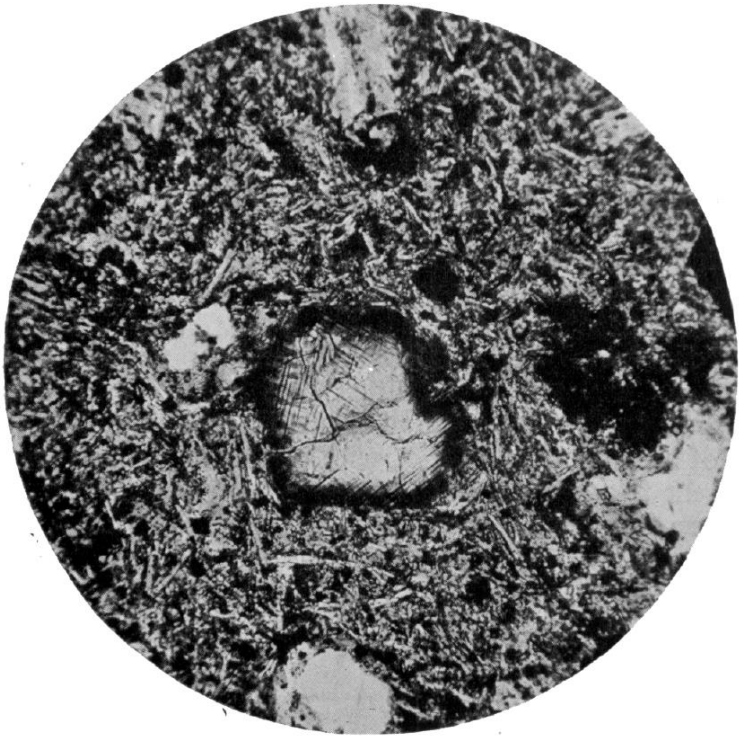

Fig. 5. *Photomicrograph of Specimen No. 7. Ordinary Light, ×100.* Taken at the higher magnification of 100 diameters in order to show the details of one of the haüynite crystals, with its very dark margin, and incompletely developed cleavage. The character of the groundmass is a little more plainly exhibited, also.

Megascopically No.7 is moderately porphyritic, very fine texture as to groundmass, dark gray in color, with phenocrysts of plagioclase up to a centimeter in length, and of augite ranging in size to 7mm as a maximum. No. 8 is essentially the same as No. 7, but the augite is not so prominent. No. 9 is similar to Nos. 7 and 8. As may be seen from the chemical analysis, No. 7 is strikingly similar in composition to Nos. 1 and 2.

Comment on Analyses

The chemical analyses, Table 1, of Nos. 1, 2 and 7 are similar, but No.3 has lower silica, higher lime, higher magnesia and higher combined iron oxides. The total alkali in Nos. 1 and 2 is about the same, nine percent approximately, whereas in Nos. 3 and 7 the total alkali is about eight percent. In other respects, Nos. 1, 2 and 7 are nearly alike in composition, especially in their content of lime, magnesia, alumina and approximately of silica and total iron oxides. All of the rocks carry a little sulphuric anhydride which, together with the high alkali, the lime and alumina, is reflected in their mineralogy by the presence of the feldspathoid haüynite and by the probable presence of nephelite as the minute crystals mentioned in the description of these rocks. Potash is higher than usual in rocks of this general composition, occurring in part as shells or coatings of orthoclase on some of the plagioclase phenocrysts, in part as little crystals of orthoclase distributed through the glassy base of the rocks, and probably in part in "occult" form in the glassy base. Nos. 1, 2 and 7 are andesitic, whereas No. 3 is basaltic. According to the Quantitative System nephelite occurs in the norm of all four of the rocks, with olivine and diopside. The prominent feldspathoid in the mode is haüynite, with nephelite of less certain identification.

COLUMBIA UNIVERSITY,
NEW YORK

Location map of the volcano Sumaco